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Undersea Photography in Marine Research

By R. E. CRAIG, B.Sc., A.Inst.P.,
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FOR SCOTLAND

MARINE RESEARCH

1963 No. 1

Undersea Photography in Marine Research

By R. E. Craig, B.Sc., A. Inst. P., and R. Priestley
Marine Laboratory, Aberdeen

With an Appendix by C. G. Wynne, B.A., Ph.D., F. Inst. P.

January, 1963

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1963

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Undersea Photography in Marine Research

INTRODUCTION

The last ten years have seen a steady development in the application of undersea photography to fishery research. It is the object of this paper to describe in some detail the techniques developed at the Marine Laboratory, Aberdeen, to meet these applications. These techniques are not particularly complicated in principle, but sound engineering design and careful execution are essential if equipment is to be reliable and satisfactory. For some details of design and for his supervision of the engineering work, we are indebted to Mr. W. H. Burgess, the technical officer in charge of the workshops staff of the Marine Laboratory.

In fisheries research and other branches of oceanography, problems posed usually have in common one outstanding characteristic. They require conclusions about phenomena hidden beneath the surface of the sea. The objects of study are inaccessible and all observations are necessarily indirect.

This indirectness of observation has two important consequences in marine research. Firstly, in the initial stages of any study, there tends to be an aura of vagueness until at length a mental picture is built up from the jig-saw pieces of many observations. Secondly, once a consistent picture has been built up, it tends to take the place of reality and to be accepted with less challenge than is desirable.

More direct observation is thus necessary to test, and aid the re-assessment of, hypotheses. There are three outstanding developments in this connection—acoustic search, photography and television. Of these, acoustic methods, echosounding and asdic, have so far made the greatest contribution, the more so as they have already lent themselves to war-time and industrial uses. Television and photography fill the need for more detailed short-range study. Of these we have found photography, on account of its greater cheapness and adaptability, easier to apply and more suited to observations that do not require the immediate awareness or lengthy observation that are the prime values of television.

Among the many problems capable of solution by photography are descriptions of the sea-bed and the fish and larger animals upon it, the study of mid-water organisms, the study of the action of fishing gear and the viewing of indicating instruments *in situ*. Detailed description of complete equipment would involve much repetition. It is considered useful to analyse the techniques and to submit their elements to separate study.

PRESSURE CASES

Materials

Phosphor-bronze castings

These are probably the best from the point of view of corrosion, but they tend to be excessively heavy. If the castings are not of the best quality, pitting and leaks due to porosity may occur. Where these are not severe they may be remedied by impregnation with a plastic such as bakelite or polystyrene, a process carried out by a number of specialist firms at reasonably low cost. In Aberdeen phosphor-bronze castings were used for the first few cameras, but their weight and cost have led to the abandonment of this material.

Aluminium alloy castings

A suitable alloy is Alpax or, for highly stressed cases, Alpax-beta (L.33). This material seems to be eminently suitable for large cases where the weight would otherwise be excessive. It is apt to become corroded and pitted under the action of sea water, but not prohibitively so. To keep corrosion within acceptable limits, however, no exposed brass or copper should be placed in the vicinity of the alloy underwater since they cause heavy electrolytic action. Expendable magnesium anodes should be used to minimise any residual electrolysis due to mountings, etc., for the case.

If the material has to be tapped for any glands, studs, or other attachments, a very coarse thread should be used, as this alloy does not accept fine threads. Stainless steel, monel metal, or cadmium plated mild-steel are suitable for screws or studs in this material, though this last is apt to cause trouble when the plating wears off. As with phosphor-bronze castings, leaks due to porosity may occur, and can be remedied in a similar way. Porosity or flaws occurring at a face to be machined may require the condemnation of the whole casting.

Brass, steel or aluminium drawn tubing

All these are suitable materials, though drawn aluminium tube has not been used at the Aberdeen Laboratory. Fabrication from tube is much the quickest and cheapest way of making cases, where the numbers required do not offset the high cost of patterns for a casting. Ends will normally have to be cast though where they can be made from plate or solid bar this is much more satisfactory. Brazing has been found to have a limited life in sea water, and welded steel when well cared for seems to be more reliable.

The protection of steel from rust is obviously important, and zinc spraying of the finished article gives an excellent protective coat and provides a good base for paint. Surfaces which have to be perfectly smooth for sealing cannot be sprayed, and these have to be well protected with silicone grease, which is compatible with rubber seals and does not cause them to perish.

Tufnol tube

This is a suitable material for cases intended for a limited depth—perhaps 30 fathoms. It is not corroded in sea water and is comparatively light.

Design

Watertightness is, of course, essential and three sealing problems are encountered.

Lid seals

Only two types of seal are worth considering. In both the sealing element is a rubber or neoprene O-ring, details of which can be obtained from the makers. Figures 1(*a*) and (*b*) showing a seal of the piston type are self explanatory. This seal is extremely neat; even pressure on the O-ring is assured by

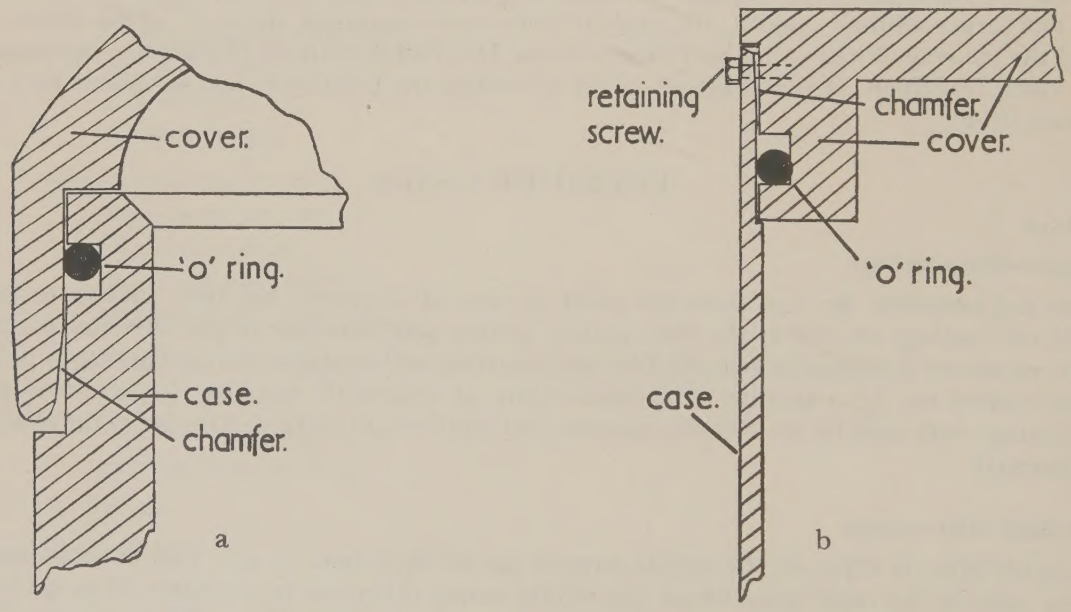


Fig. 1. Piston seal (*a*) with external lid (*b*) with internal lid.

the construction, and the retaining screws or clips can be light and easily removed, as they have no stresses to withstand. Two points should be emphasised. Firstly the clearances specified by the manufacturers are intended for moving pistons and the precise machining which is naturally to be associated with such parts. It is desirable to provide groove depths of the order of 0·020 inch (0·5 mm) less than those specified. This gives increased pressure on the O-ring and excessive tightness can be more easily remedied than slackness. Secondly, it is sometimes difficult to remove a lid sealed in this way, so, where there is space to do it, it is advisable to provide some positive means of lifting the lid such as lifting cams or screws.

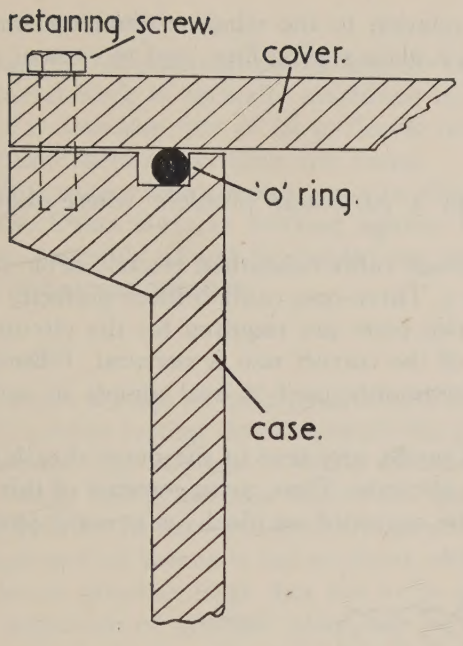


Fig. 2. Face seal using a circle of retaining screws.

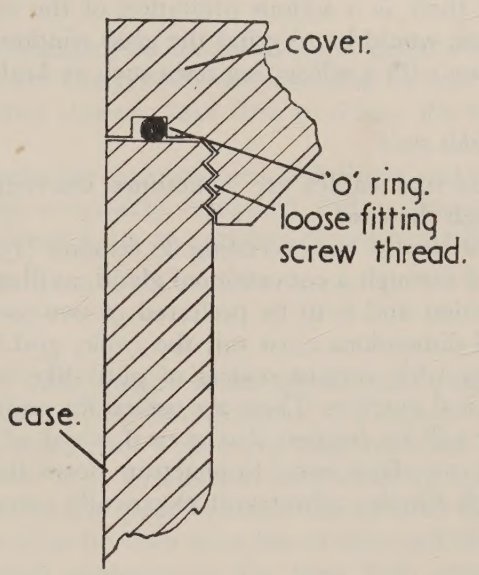


Fig. 3. Alternative face seal (after Laughton).

Figure 2 shows a flat seal, which is less neat in that it requires the provision of a heavy flange inside or outside the case and thus adds to the weight and diameter of the unit. Also the retaining screws have to provide enough force to give initial compression to the O-ring and seat the lid evenly all round. An alternative arrangement provides pressure on the centre of the lid via a clamp and large central screw.

A neat variant of this seal has been described by Laughton (1957). This is suitable for small lids (Fig. 3) where the lid can be screwed directly into the case. With this arrangement, the screw threads have to be a slack fit on one another, so that the sealing faces can be pulled down flat together, and be held so under pressure at great depths. In designing these flat seals it should be noted that the O-ring manufacturers specify groove diameters to resist internal pressure. The internal diameter of the groove should be the same as that of the O-ring.

Window seals

Here again the O-ring provides the most satisfactory solution, and alternatives are not worth considering unless space is severely limited. Figure 4 shows a typical arrangement. The form of clamping

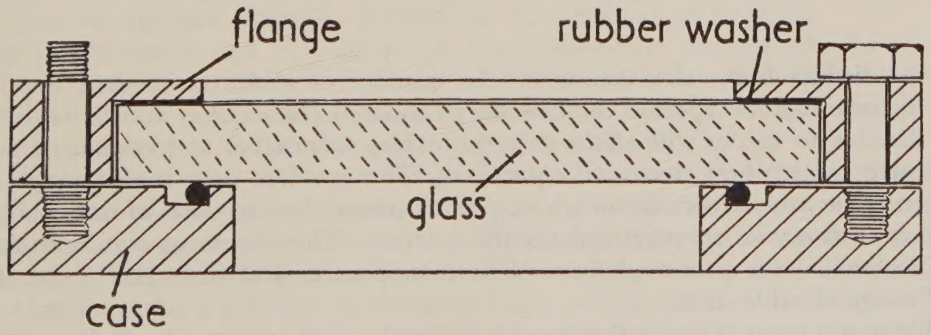


Fig. 4. Arrangement of window seal.

ring used to hold the glass in place is not important, so long as the glass can be brought firmly against the sealing face without severe local stresses likely to cause cracking or chipping. A minimum of six screws or studs is desirable for small windows, and considerably more for large windows.

If there is a serious limitation of the seal diameter in relation to the window diameter, the best solution would be to grind the glass window in contact with a plain sealing face, and to cement it into position with a self-setting resin such as Araldite.

Cable seals

External cables are sometimes unavoidable and present a particular problem where they pass through the case.

For depths not exceeding 80 fathoms (150 m) ordinary tough rubber-sheathed electric cable can be passed through a conventional gland, as illustrated in Figure 5. Three-core cable is more perfectly round in section and is to be preferred to two-core, even if only two cores are required for the circuit. The gland dimensions must suit the cable, and a rubber insert of the correct size is essential. Fibre gland fillings with various sealers of putty-like consistency are commonly used to seal glands in ordinary electrical practice. These are useless for underwater work.

It will be realised that even if a seal of this type is well made, any tear in the outer sheath of the cable can allow water to penetrate down the cable and into the case. Thus, arrangements of this kind, though simple, robust and electrically convenient, cannot be regarded as ideal for general purposes.

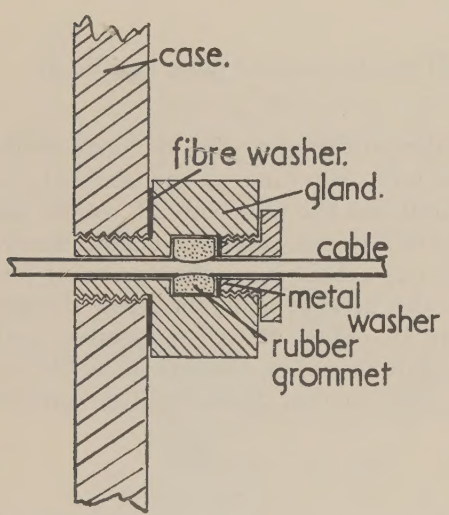


Fig. 5. Cable gland for depths of less than 80 fathoms.

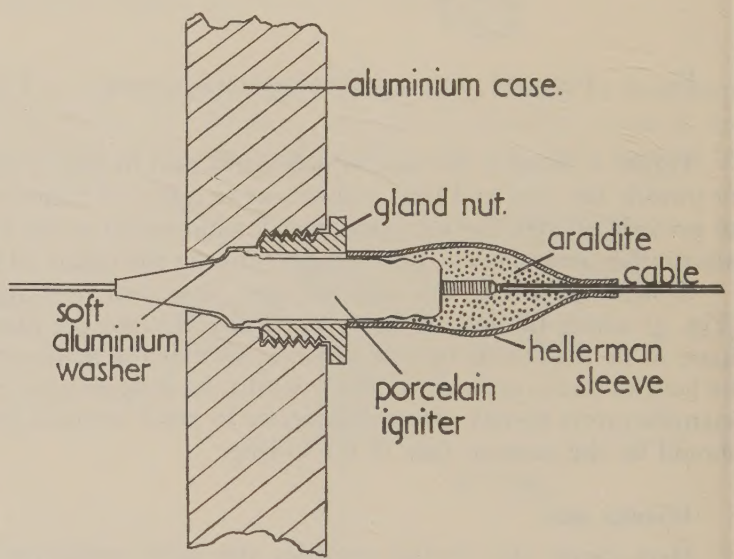


Fig. 6. Porcelain lead-in for depths greater than 80 fathoms.

In camera as distinct from television work, the number of cable connections required is usually small, so that the case can incorporate the necessary insulated connections and be entirely waterproof. Consequently damage to cables will affect only the cables themselves and cannot cause leakage into the more expensive camera and electronic equipment. The problem then is to arrange electrical connections between cable and camera in such a way as to ensure the exclusion of water and continuity of insulation. Figure 6 shows an arrangement for this purpose. The sleeves used to seal the cable to the lead-through insulators were produced from Hellerman plastic, and since this is an elastic material they fit a good range of cable sizes.

It is desirable to use types of sleeve that can be easily obtained in quantity. Cable ends—particularly in light cable—are easily damaged. For instance, a rubber sleeve can be vulcanised on to a cable to give an excellent seal of this kind, but in the event of damage repairs on the spot would not be feasible.

Variants of this technique include the cementing of the porcelain insulator directly in position with Araldite. This also is effective, but a breakage of the porcelain insulator would put the equipment out of action for a long time.

General considerations

A number of practical points have to be observed in the design and manufacture of camera cases. Since metal work is normally machined to order, while rubber components are moulded by specialist firms, it is desirable first of all to decide on the rubber sealing elements and then to design the metal work round them rather than vice versa.

Sealing surfaces for windows must be absolutely flat, otherwise the high pressures will distort and crack the glass. Other surfaces working against O-rings should be accurately machined and as smooth as possible. Assembly should be carried out most carefully, as loose hairs or particles of grit can cause a seal to leak under pressure.

WINDOWS

Windows are apt to be expensive and difficult to obtain. Good quality white optical glass windows are produced by casting. Small optically flat glasses of about 4 inches (100 mm) diameter by $\frac{3}{8}$ inch (10 mm) thickness are easy enough to obtain to order, but glasses of more than $\frac{1}{2}$ inch (13 mm) thickness may involve long delays because blanks are not readily available. It is considered worthwhile to specify optical glass for camera windows, but to accept ordinary heavy plate glass for larger windows for lights, for which optical flatness is not required, although thick plate glass involves some loss of light and always has a heavy greenish tinge that has to be allowed for in colour photography. For these light windows heavy aquarium or porthole glass may be most readily obtained.

OPTICS

The only special optical consideration in underwater camera design is that the scene to be photographed is immersed in water, while the camera is inside its case in air. The immediate effect of looking into water is to make objects appear nearer. The refractive index of sea water is 1·34, and an object at a true distance D appears at an apparent distance of D/1·34. Thus the first simple rule is to set the camera focus at 3 feet for a true distance of 4 feet, and so on. Unfortunately the transition from water to air introduces other difficulties, and measures must be taken to combat these.

The most serious are chromatic aberration and curvature of field, which are discussed in greater detail in Appendix I. Curvature of field is only of importance in bottom photography, when sharp definition of the fairly level sea-bed is required. In mid-water work there is a large element of luck in finding the subject at the required range, and it does not matter whether the zone of sharp focus is plane or curved. Chromatic aberration is serious in all types of photography underwater. It arises from the dispersion of light by water, i.e. its differing refractive power for different colours of light. There is no trouble from this cause in the centre of the field, but it becomes significant towards the edge of the field, and in general may be regarded as serious beyond 10° from the axis of the lens.

Considerable improvement can be achieved in black-and-white photography by the use of filters either over the lens or over the source of light, to remove the blue, violet and ultra-violet components of the light. This is recommended if other means of correction are not available, though it necessitates the use of larger lens apertures and a consequent loss of depth of field.

For colour photography, other means have to be found. Two methods have been used with success. In the first the flat glass window of the camera is replaced by a spherically curved window. The lens is placed at the centre of curvature, and so 'looks' straight through the water-air boundary. The curvature of the water boundary makes it act as a negative lens, so the image to be focused is brought still closer to the camera. Also, since this is a simple uncorrected lens it is subject to spherical aberration and all the other natural aberrations of such a system. Nevertheless, this system gives good photographic results and the loss of definition is tolerable for many purposes. The main objections to it are mechanical; the necessarily large gap between lens and window is a waste of valuable space, and the curved window is large and fragile, compared to a small flat window close to the lens.

To overcome these difficulties it was thought best to obtain a lens corrected to eliminate the flat window errors. Such a lens, designed by Dr. C. G. Wynne, has proved successful (see Appendix II).

The use of corrected lenses is regarded as the best available technique, but it suffers from th limitation that changes in format, or changes of technique requiring different focal lengths, ma necessitate the designing of a new lens, and this unfortunately is neither quick nor cheap.

CAMERAS

Still Cameras

The chief requirement is the capacity to take a large number of exposures without excessive powe drain, and with simple and reliable triggering. In some ways the requirements are similar to thos involved in the recording of cathode-ray tube traces.

Unfortunately a large number of recording cameras have been built without regard to the need fo compactness that is so important in underwater work, and the choice of camera is restricted. Fo deep-water work, where natural light is negligible simplification can be achieved by the omission of shutter. A specialised camera can then be assembled involving only a lens and film transport system a described by Laughton (1957). In Aberdeen it has been necessary to consider regions where natura light is appreciable and so a shutter is required. It has seemed impracticable to design cameras specifically for underwater applications.

The first essential is to decide upon the most suitable format. A square negative form is a reasonabl one to adopt, and the only sizes worth serious consideration are 35 mm film with a negative about 1 inc (24 mm) square and 70 mm film with a negative about 2 inches (48 mm) square. Both these sizes ar available as perforated film in long lengths, and facilities for bulk processing can be arranged. Losses o information due to film grain must be balanced against losses due to bad focus. There is no doubt tha for sea-bed work, where focusing can be precise, the 70 mm film is capable of giving the greater amoun of information. For mid-water work the advantage lies with the 35 mm size, which has been adopte at Aberdeen largely as a matter of convenience, and because of the availability of a variety of black an white and colour films in this size. Nevertheless, for new equipment for benthic surveys, the availabl 70 mm cameras deserve serious consideration.

The camera used at the Marine Laboratory is the Shackman Auto Camera. This takes more tha 20 ft of 35 mm film. The film rewind is operated by clockwork, and the shutter is worked by a 24 V solenoid. This camera may be triggered by a discharge from a large condenser of 2,200 μF capacity This arrangement has certain merits in avoiding double exposures and the need for a very brief contac in the trigger system.

Some early work was done with the Robot automatic camera, which has a much smaller film capacity and in which the electrical triggering has to be provided externally. It is, however, more compact an can be fitted in a smaller case.

Excellent sea-bed results have also been obtained with a much larger camera, the ex-R.A.F. type F.2 aerial camera, with a format of 5 inches square. This unit is rather bulky and unsuitable for mid-wate work.

The Shackman Auto-Cameras are fitted with the Wray Underwater unilite lens (see page 23), whic has a maximum aperture of about $f/3$. The shutter is removed from its usual position and mounte centrally in the lens to avoid vignetting.

Cine Cameras

There is a wealth of small cine cameras available but the main considerations are electric drive an the balancing of cost against performance and film capacity. For use by divers the Vinten 16 m scientific camera, an instrument of convenient shape in the intermediate price range, has been adopte at Aberdeen. For diving work the fastest available film is used, as lack of focus is usually more seriou than film grain.

In the trawl net the 8 mm Eumig electric camera has been adopted. This is small and convenient t use, and its comparatively low price makes it suitable for attachment on gear in situations where los or damage is more or less certain to occur in time. The low cost of 8 mm film is also an advantage coupled with the great depth of focus available.

It is not suggested, however, that 8 mm format is definitely preferable to 16 mm for such applications. Experience may show the cost of 16 mm equipment to be justified by the better resolution obtainable.

LIGHTING

In clear water, sufficient light for still or cine photography exists down to a depth of about ten fathoms (20 m). This is true on bright summer days in Scottish waters for about three hours on either side of noon. Natural light has been used for nearly all photography by divers.

If natural light is adequate it provides the best illumination for long range photography as it is uniform in intensity and does not vary with the distance from the camera.

For most other purposes, however, artificial lighting of some sort is required. For cine work this lighting has to be either continuous or rapidly intermittent as provided by a stroboscope synchronised with the camera motor. The latter method has not been employed at Aberdeen but it might be the best solution for some purposes. Its main advantage is that it provides a flash of short duration for each exposure, thus reducing blurring caused by movement of either the camera or the subject. This is of undoubted advantage where the film is to be examined frame by frame. It is not clear that any advantage would be gained if the film were projected and viewed at true speed on a screen.

The main objections to stroboscopic illumination for cine work are its greater complexity and the higher voltages involved in comparison with steady lighting. Also, while in principle it makes better use of *light energy*, it seems that, when the practical details are considered, it is no more efficient in terms of the *electrical energy* which, after all, is what affects the bulk and weight of the complete unit.

Optimum fixed artificial lights for cine photography can be realised when a section of the sea is turned into an underwater studio. This can be done by a team of divers, or can be arranged in shallow water for a few specialized operations. Lights are placed independently of the camera, and each position selected to illuminate important features of the scene. Such methods are the most successful when they can be applied; moreover, they bear an obvious relationship to ordinary photography ashore.

Normally in research work the object of underwater photography is to view the inaccessible, and for this purpose a robust self-contained unit is essential. The first requirements are that for efficiency the available light should be spread evenly over the field of view of the camera, and that power should not be wasted by the illumination of areas outside this field. Approximation to this ideal has to be achieved by the suitable choice of lamp and reflector and by the correct positioning of these in relation to one another. For some tasks 'reflector spotlights', manufactured for shop window illumination, will be found to give a convenient and compact source of light. These have been consistently used at Aberdeen for television.

Another very important condition for underwater work is that the region immediately in front of the lens must not be illuminated, unless it is the subject of investigation. There is always suspended matter in the sea, and if this material is brightly lit by a close-up lamp it will appear over-exposed in the picture, thus blotting out the required detail beyond. In practice this means that the lighting must be placed well away from the camera lens and window, the limit generally being imposed by the need for compact equipment.

Any lighting involves watertight fittings, and generally windows, with consequent risk of failure. It is, therefore, considered good practice to provide a single source of light and place it so as to give the most efficient illumination possible.

Any self-contained equipment, in which the camera and light are combined in a single unit, suffers from the limitation that the intensity of light on the subject varies with the distance of the subject. In sea-bed photography this is not serious, because the whole subject can be at roughly the same range. However, in mid-water work, or when looking horizontally across the sea-bed, the ratio of the distance of the nearest to that of the furthest object that can receive a correct exposure is only about 2:3. This demonstrates the advantages of natural light or studio-type lighting, which are not, however, always possible.

As in most photography the simplest rule about light is to provide as much as practicable. In this way small lens apertures can be used to obtain good depth of field, and fine-grained films can be employed to reproduce the detail available from a good optical system. Accordingly, mains lighting

from a ship's generator will commend itself if convenient. The trawl-net cine camera described on page 1 uses a 75 W 12 V car spotlight bulb. This can be run from a Nickel-Cadmium hermetically-sealed battery, which occupies approximately a 5 inch (13 cm) cube, and weighs about 3 lb (1·4 Kg). Efficiency in this kind of work will march hand-in-hand with development in battery design.

For still photography, flash bulbs have been used for minor work by divers. For serious work where many exposures are required, electronic flash lighting is the only possible choice. The useful light in relation to the power supplied, is several hundred times more effective than continuous lighting, and the 'stopping power' of the brief flash can provide a sharp image of even fast-moving subjects. Furthermore if electronic flash is adopted, there is no need for the camera to be held steady—a condition which is difficult to ensure in any work from ships at sea.

Precisely the same considerations arise about reflectors and positioning of the light, as already discussed for continuous lighting. The light source should be well away from the camera window, and the region just in front of the camera must not be illuminated.

A wide range of flash tubes is available, and various types, ranging in power from 1000 joules down to 50 joules, with a voltage of from 2,500 to 550, have been used. These lower voltage tubes were of a type designed to operate with a minimum voltage of 180, but they have been found more reliable when used at a somewhat higher voltage.

The large sea-bed cameras described below are mains operated and use a 500 joule tube. The trawl-net camera described on page 14 is limited by its battery supply to much lower power, and a 50 joule tube is used.

The value of this type of lighting is shown by the fact that the light from the 500 joule tube is more than half a million candle-power, and lasts for about 1 millisecond. This light intensity would require about half a megawatt of continuous lighting. For comparison it might be regarded as the equivalent of an exposure of $\frac{1}{50}$ second with steady lighting. The corresponding value of lighting power would then be 25 kW. In the camera, the peak power taken is 250 W and the average about 150 W. Electronic flash tubes are suitable for use with daylight colour film, but a filter excluding ultra-violet light is advisable.

ELECTRICAL EQUIPMENT

Electrical power is required for lighting and control, and frequently also to give information to the operator. Reliability, compactness, ease of maintenance, cheapness and ease of construction have to be considered carefully when choosing equipment.

Mains-operated Cameras

Mains operated units, useable from research ships for sea-bed or mid-water photography, produce the best photographic results. With ample light they are capable of producing photographs, in colour or black and white, of the finest quality. The electrical arrangements are dictated largely by the requirements of the cable linking them to the operator on board ship.

Separate electrical cable is inconvenient except in shallow water, because it has to be lashed at intervals to the lifting cable, and this seriously slows operations. A standard cable has, therefore, been adopted to combine the functions of supporting the camera and supplying it with power and means of control. This is a high-tensile steel wire with a single core of stranded copper insulated with polythene.

The borehole cable, as it is called, is wound on a barrel made to fit over the warping drum of a trawl winch. Slip-rings (Fig. 7) are fitted to this barrel to feed the power supplies through the cable. These supplies are a.c. 50 c/s fed via an isolating transformer. The side passed via the outer wire can be earthed. Some stepping up of the 230 V supply, for example to about 260 V, is done by the isolating transformer to compensate for voltage drop in the long and relatively light electrical cable.

It was required to use this single core cable to provide—

control of exposures from the deck,

control of exposures by a trigger weight suspended from the camera, and

information at the surface about the correct operation of the camera and its triggering when the weight strikes the sea bed.

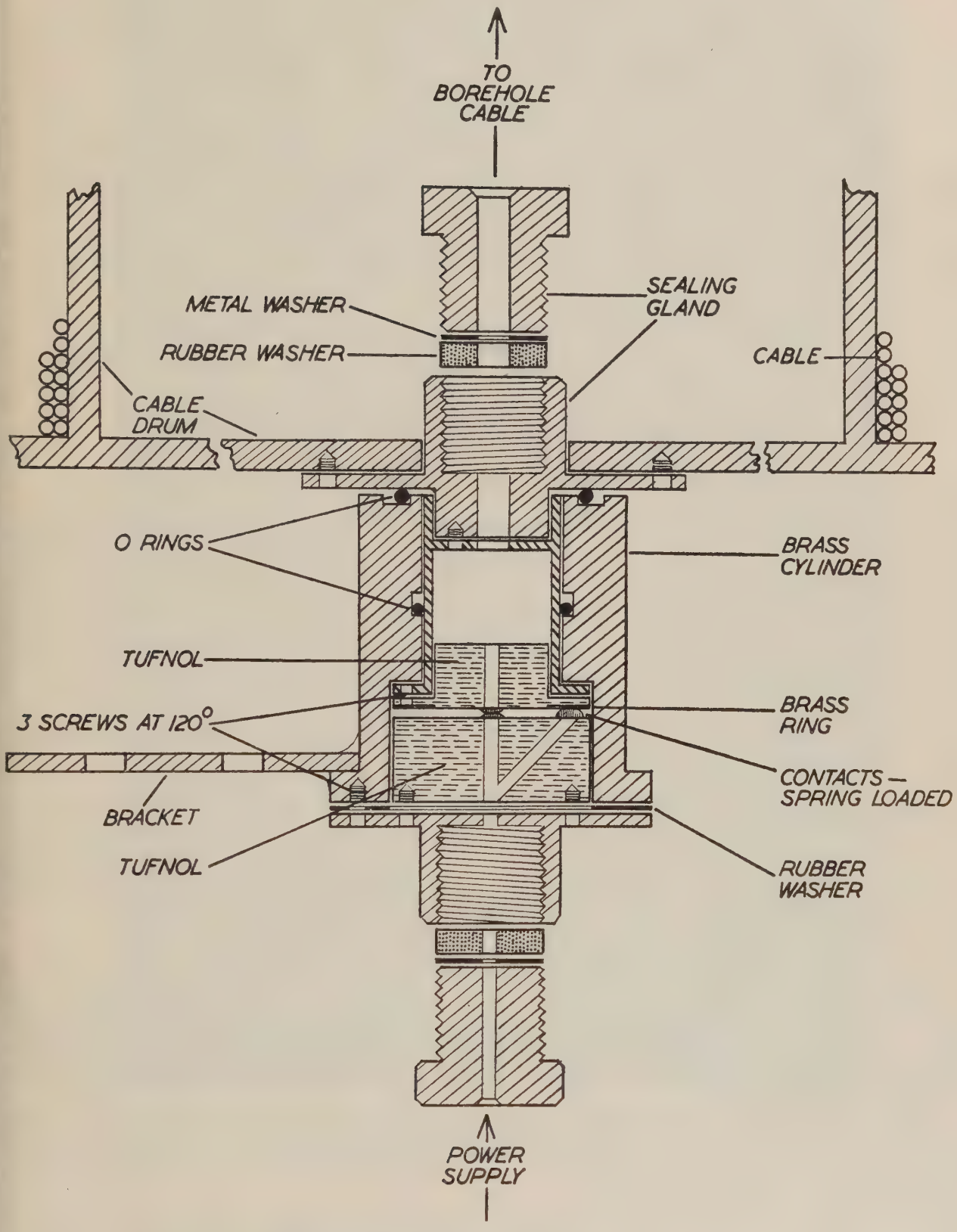


Fig. 7. Slip rings for leading power supplies through winch.

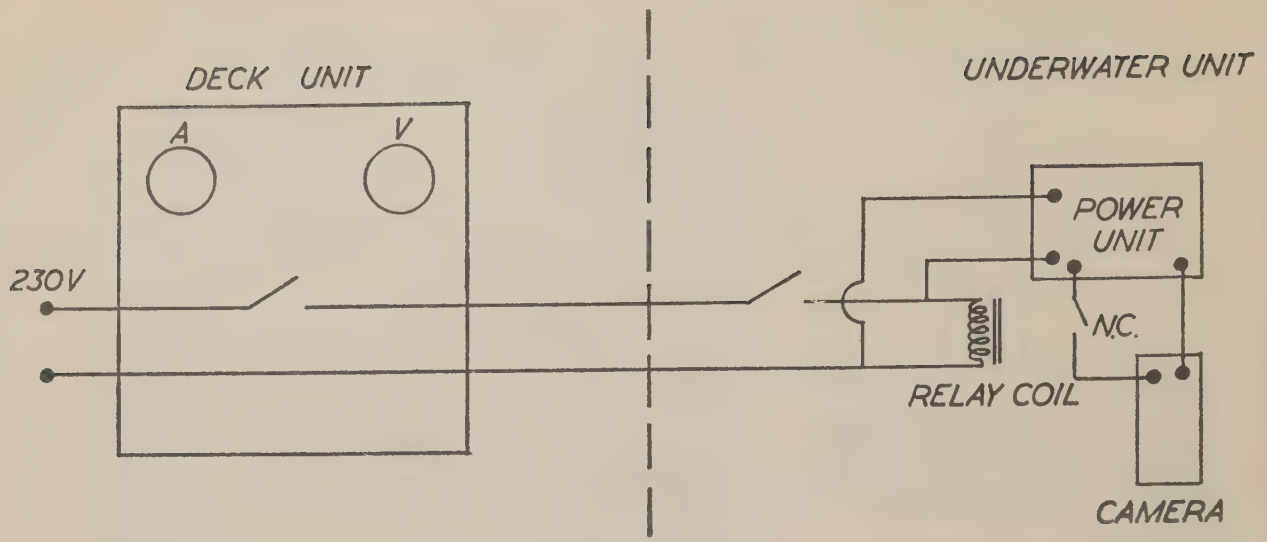


Fig. 8. Illustrating control system for sea-bed cameras (see text).

To do this a system as in Figure 8 is used (see also Fig. 11). The a.c. supplies are fed to the underwater unit via two switches, one on the deck unit and the other a magnetic switch triggered by contact with the sea-bed. It is enough to consider the action of one switch, assuming the other to be 'on'. When power is switched on, the flash power unit begins to charge a bank of condensers for the flash tube, the trigger power unit begins to charge a large condenser to about 80 V for camera triggering, and the relay connecting this condenser to the camera is opened. After about half a minute both these charging operations are complete, and the system is ready to be operated. This is done by turning off the power. The relay closes, operating the camera, and the flash is triggered in the usual way by the synchronizing contacts on the camera shutter.

Thus control from the deck is possible as required. When triggering on the sea-bed the deck switch is left 'on'. The magnetic switch at the camera is normally 'on', but when the weight strikes the sea-bed this switch goes 'off', thus operating the camera.

Information about the operation of the unit is provided by the ammeter A. Correct operation is indicated by the supply current rising to about 1 amp on switching on, then decreasing to about $\frac{1}{4}$ amp as the power units charge up. When the camera is triggered, the current drops momentarily to zero, and if operation has been correct rises again to 1 amp. The period of zero current is used to ring a bell on deck. Failure to operate correctly is immediately disclosed by the meter readings, and the general nature of the fault is usually obvious.

Battery-operated Cameras

When batteries are used, it is natural to find a conflict between the desire for adequate light and the need to keep down the weight and size of the batteries. Unless the batteries can be kept in a separately sealed compartment, they should be of an unspillable or, preferably, of a sealed type. There have been significant advances recently in the development of sealed, re-chargeable batteries with a good ratio of output to weight and bulk.

Where the power requirements allow it, there is much to be said for using replaceable dry batteries either of the usual type or of the high capacity mercury type normally employed in small hearing aids. Such batteries require routine replacement only and so approximate to the fool-proof simplicity that must be the aim of equipment designers.

Dry batteries are not well suited to supplying a brief demand for large current. The 'Mecablitz' flash unit, for example, incorporates a sealed rechargeable battery capable of providing about 80 flashes. By 'backing up' this battery with a bank of dry batteries, the number of flashes available can be increased

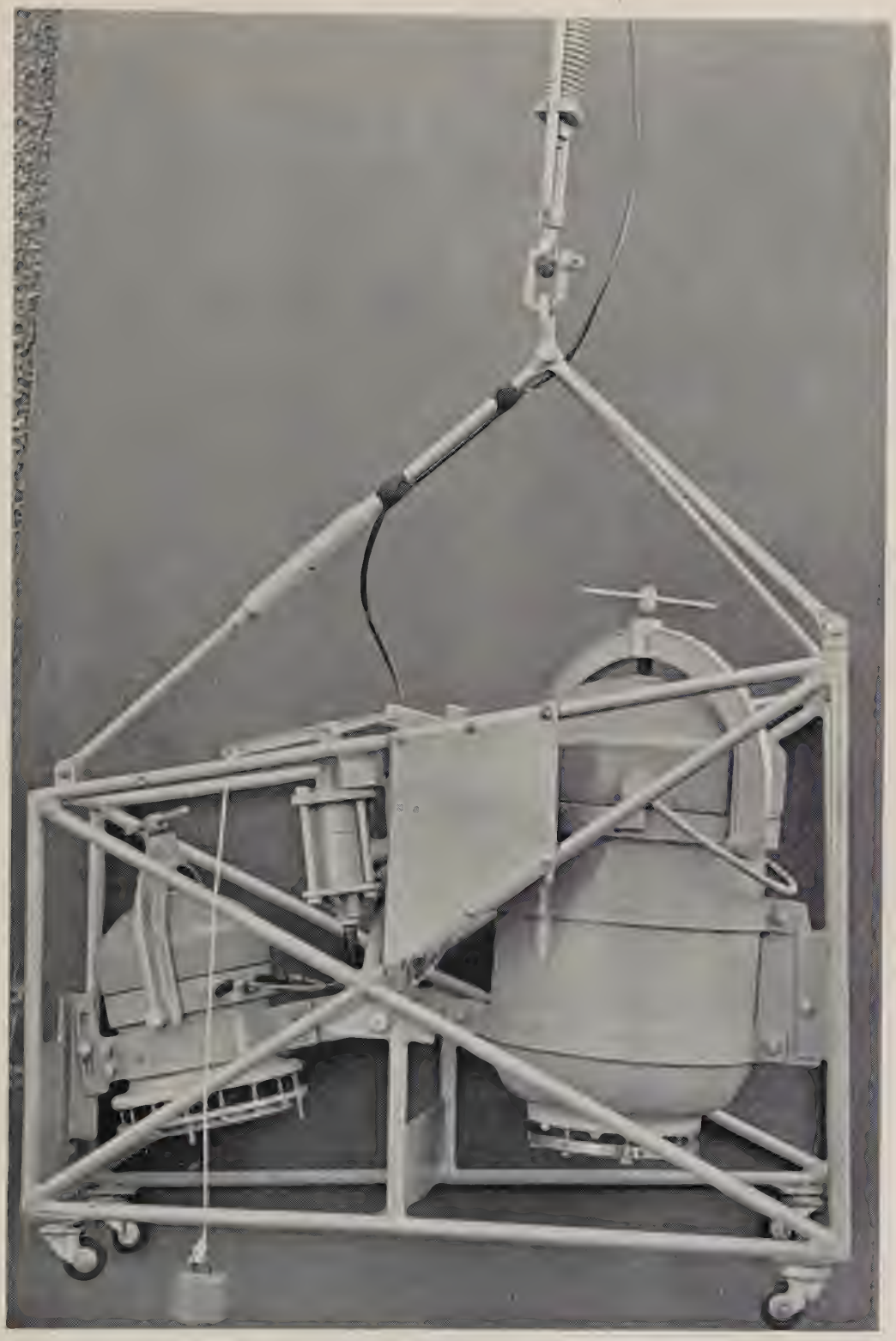


Plate IA. Mk V sea-bed camera. The trigger weight cord has been shortened to bring the weight into the picture.

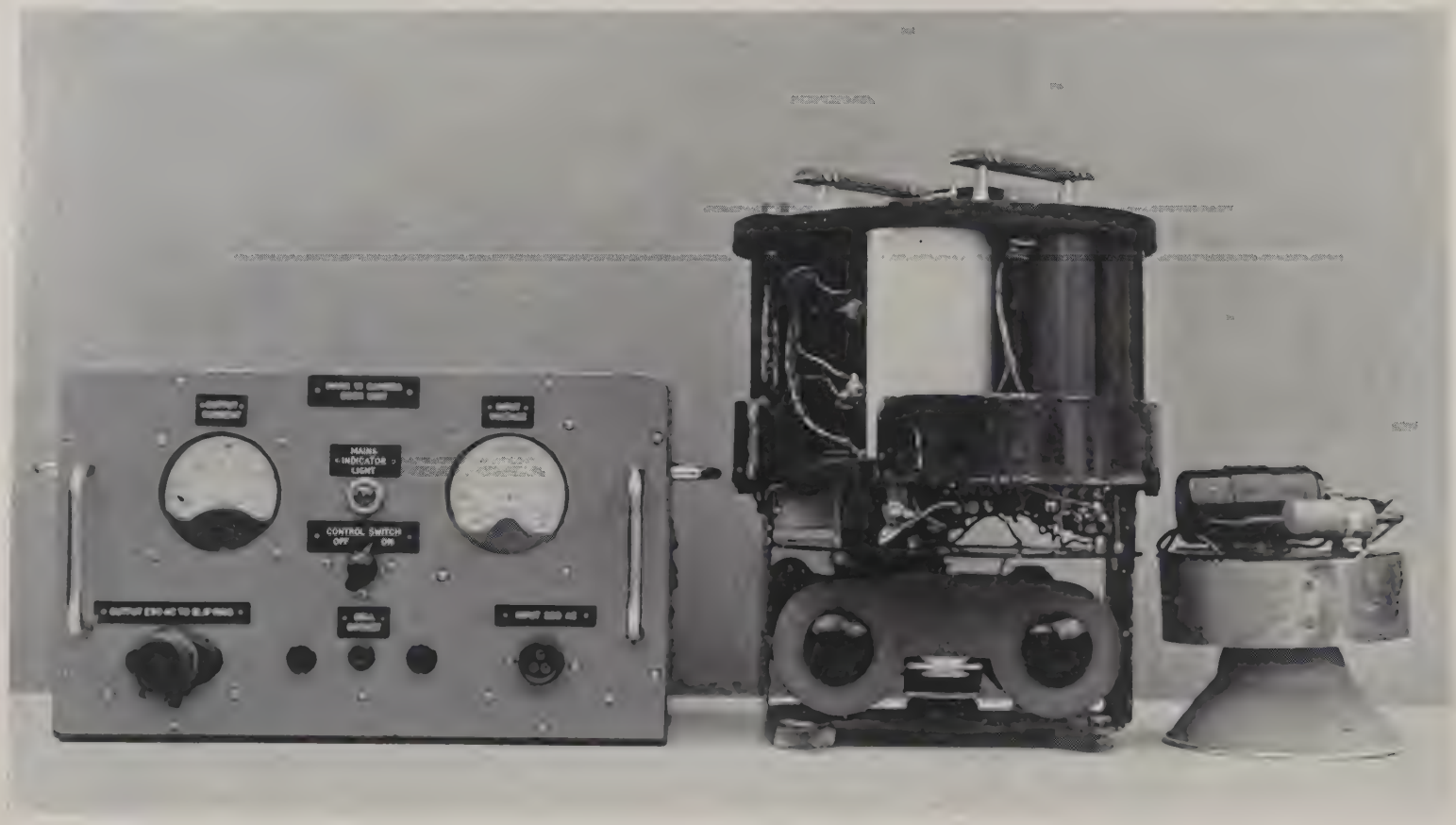


Plate IB. The deck and internal units of the Mk V sea-bed camera.

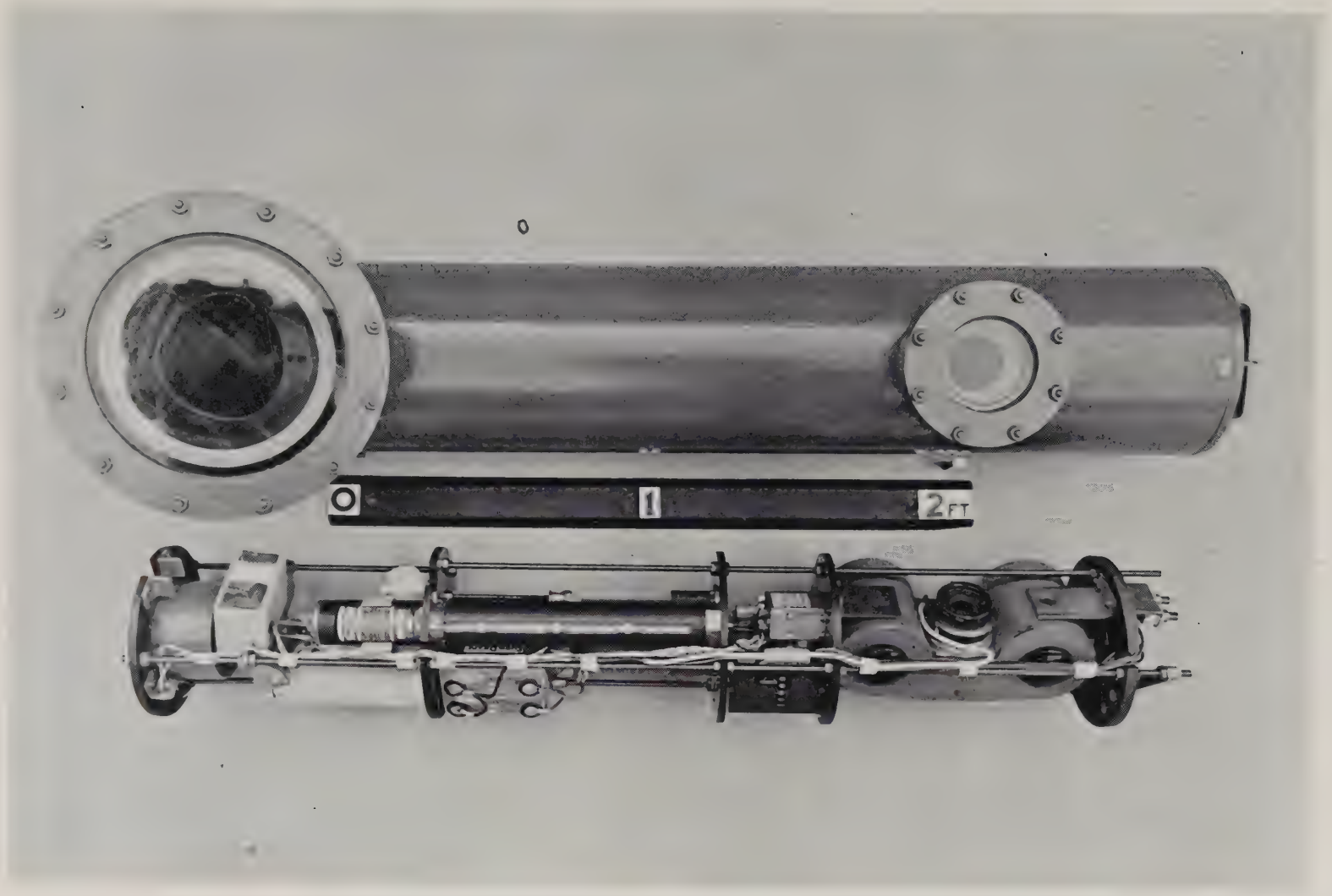


Plate II. Otter trawl camera case and (*below*) the internal unit incorporating camera and flash unit along with batteries and control gear.

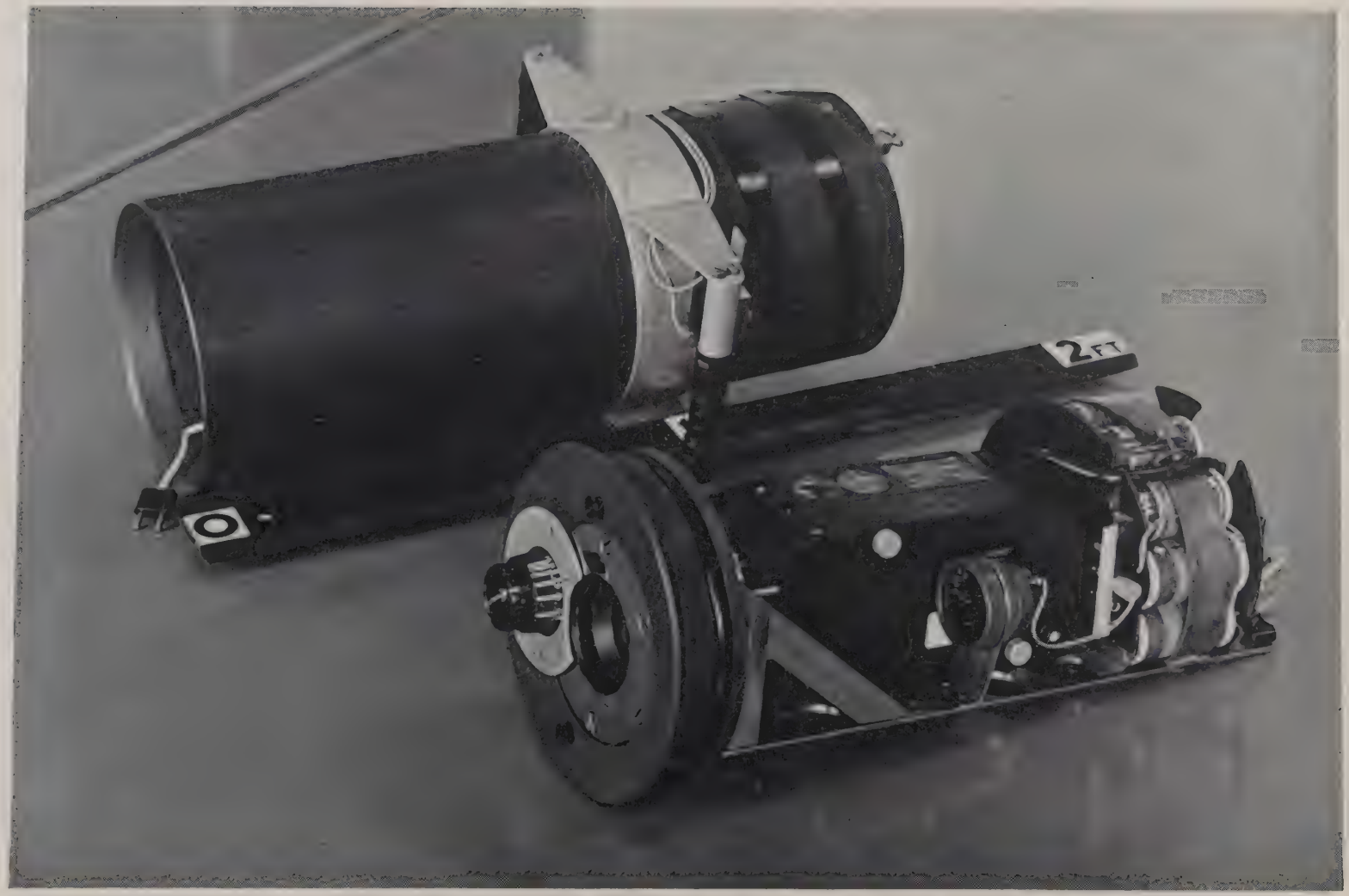


Plate III. Divers' cine camera with its Tufnol case.

Plate IV A. Sea-bed photograph from the Mk. V camera.
'Hard ground' in 30 fathoms 9 miles N. of Fraserburgh.

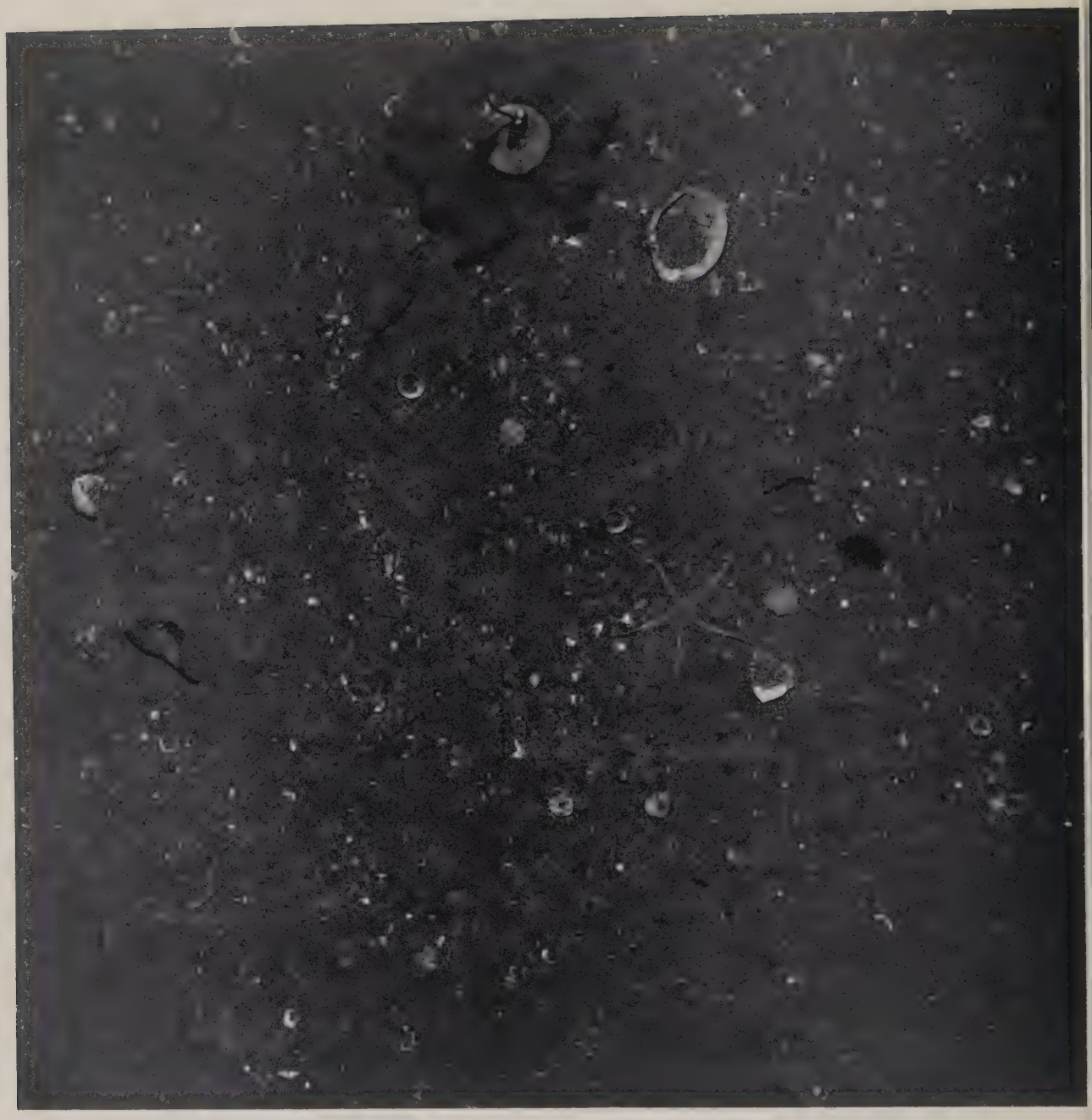


Plate IV B. Sea-bed photograph from the Mk V camera.
Fine sand in 25 fathoms 7 miles N. of Whitehills, Moray Firth.

A

B

C

D

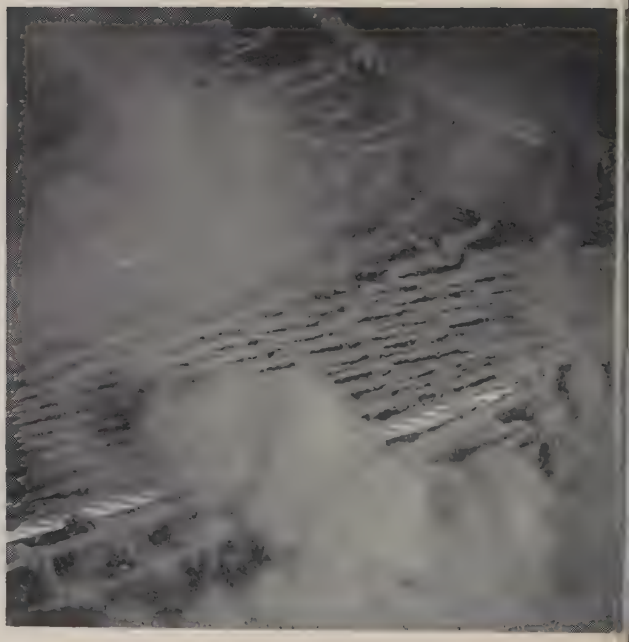
Plate V.

A. Salmon in a bag-net (static camera).
B. Herring in the vicinity of a spawning ground, Firth of Clyde (static camera).
C. and D. Camera on trawl, showing how sea-bed information can be obtained by this technique.

A

B

C



D

Plate VI. Examples of photographs taken by the camera mounted on a trawl.
A. Haddock; B. Mackerel; C. Squid; D. Trawl-net.

and the need to provide means of charging is eliminated. The dry batteries on their own cannot easily be made to meet the heavy initial current taken by the flash unit.

Control of still cameras is by time-clocks, with electrical contacts closing at pre-determined intervals. The standard interval used in the present work is one minute. By the use of an intermediate counter, or uniselector system, exposures can be spaced by any exact number of minutes.

When cameras are brought aboard from the sea-bed or from nets, re-loading, battery charging and checking may have to be done quickly in the uncomfortable surroundings of a small research vessel. Consequently it has been found necessary to make every adjustment as simple as possible, by reducing the need for tools to a minimum. Since fatigue and the general discomfort arising from the violent motion of a small ship may lead to mistakes, damage and general frustration, it is advisable to take precautionary measures and ensure quick handling of the gear.

Cine Cameras

Special timing arrangements may be required for cine cameras, and the natural arrangement would appear to be a cam or disc on which a programme of operations of a micro switch can be set up, giving a pre-set delay and a sequence of exposures. It has been found possible to provide such arrangements by modifying ex-service time clocks, but it has been impossible to obtain new equipment designed for flexibility of operation.

The trawl-net cine camera provides for a pre-set delay of up to 2 hours, from which point a sequence of seven half-minute runs takes place every six minutes.

Control Switches

All programmed cameras ought to be capable of being set up, put into their watertight cases and kept ready for instant use. Switching on must, therefore, be possible without opening the cases. This has been arranged by using a small plunger (sealed by O-rings) through the lid. The end of the plunger operates a normal tumbler switch (Fig. 9).

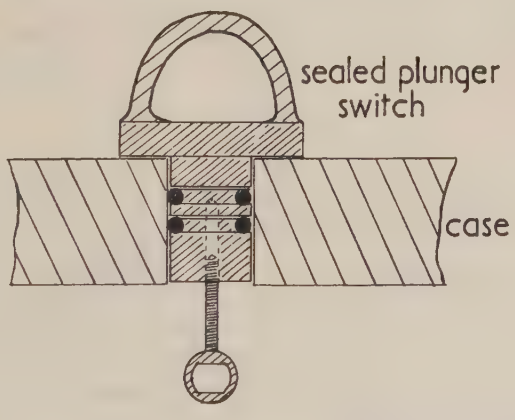


Fig. 9. Plunger to operate switches of battery-operated units.

COMPLETE EQUIPMENT

Benthos Camera Mk V

This camera is used for sea-bed surveys to a depth of 500 m. A similar unit, designated Mk VI, for use at greater depths differs only in having a heavier case and windows, and a control unit which allows for greater voltage drop in the longer cable.

This camera uses the electrical system described under 'Mains-Operated Cameras' (p. 10) and the general layout of the underwater unit is shown in Figure 10. The camera and flash tube housings are

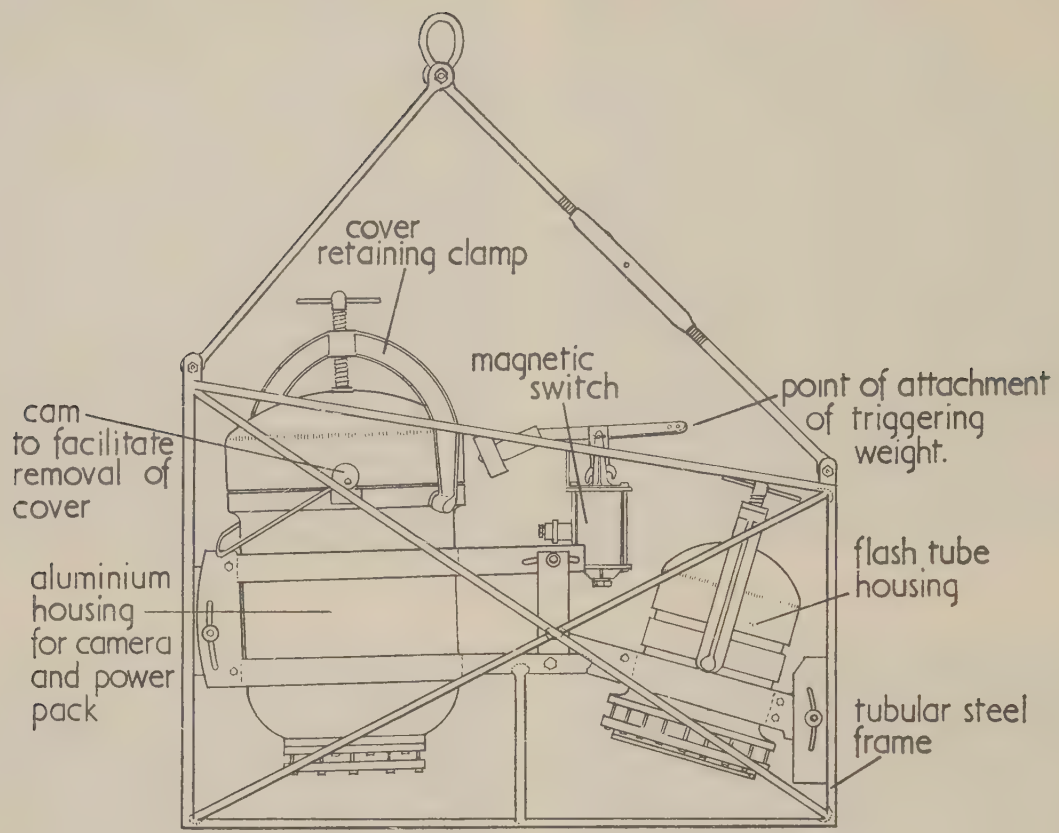


Fig. 10. Frame and mounting arrangement of Mk V sea-bed camera.

castings of aluminium alloy (Spec. L33) and the magnetic switch is of Ronald Trist type 10973X. The outer cover of this switch has to be modified to withstand water pressure by incorporating an O-ring seal.

The angles of the camera and flash tube housings can be varied, within limits, to suit the selected triggering distance. The outer cage is made of welded mild steel tubing. This type of all-enclosing cage has been found of great advantage in handling the unit at sea, not only for the protection it affords against rough handling but also for the ease with which ropes can be attached or for the steadying and recovery of the gear by means of a boathook.

The camera used is the Shackman Auto-camera with a 2 in. $f/2{\cdot}8$ underwater lens, taking 200 exposures on a 1 inch square format. The flash tube is a Mazda type FA2, rated at 500 joules. The detailed circuit diagram is shown in Figure 11, and the unit is illustrated in Plate I (A and B).

Trawl-Net Camera

This camera was designed for attachment to a trawl, but has found other applications as a fixed camera for the study of fish populations. It is a self-contained, battery-operated unit, based on the Shackman auto camera. The case is built from steel tubing as in Figure 12; the camera faces through the smaller window and the flash tube and reflector through the larger inclined window. The unit is strongly constructed to withstand hard usage (Plate II).

The circuit diagram (Fig. 13) shows that the camera is controlled by a time switch. This has a clockwork 8-days movement making a short contact once per minute, and is readily obtainable at surplus stores. To increase the flexibility of the system, a self-resetting counter has been introduced. This can be

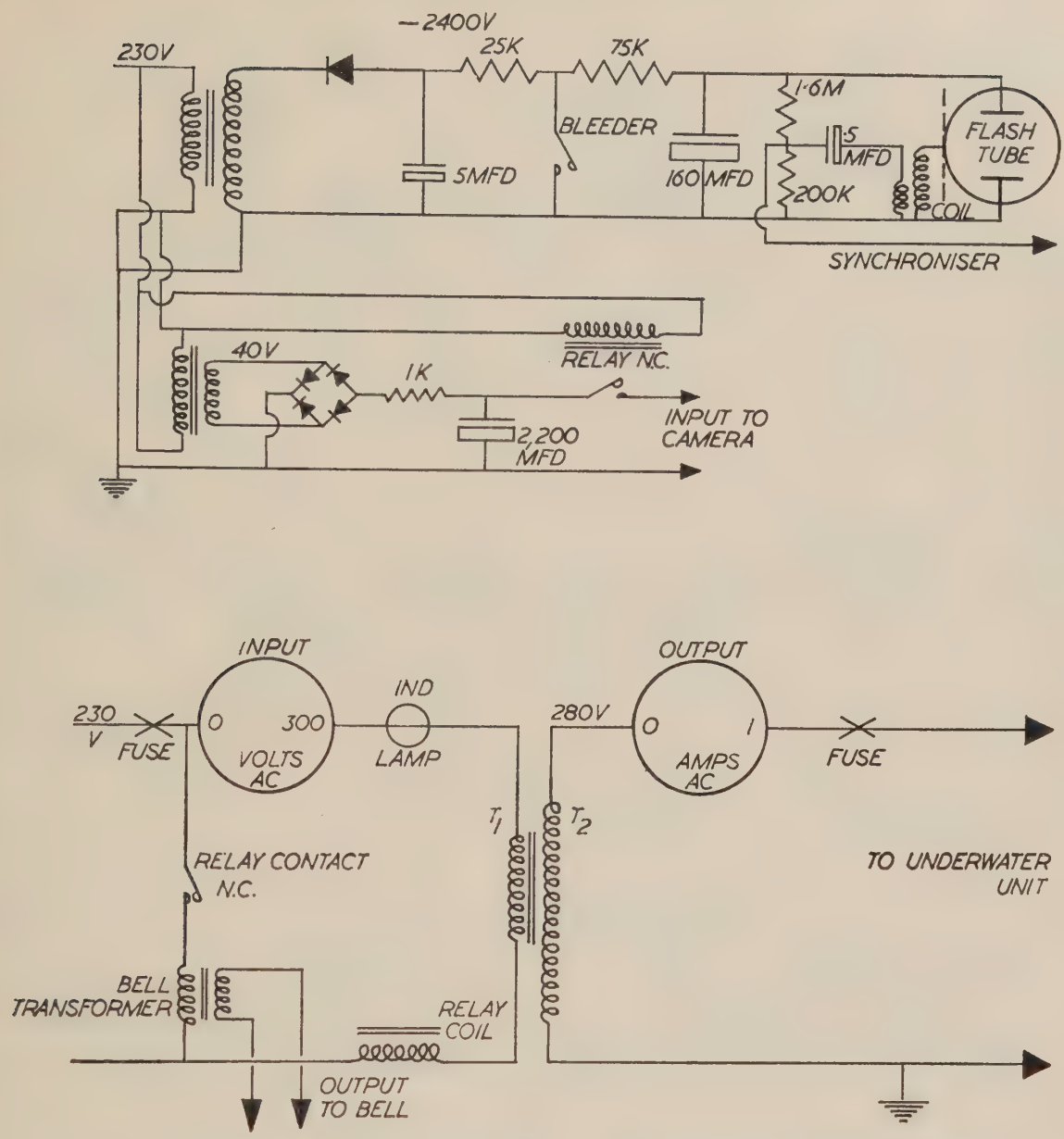


Fig. 11. Circuit arrangement of Mk V camera. The upper section is the circuitry of the underwater unit, and the lower section the deck control.

pre-set to any selected number. The counter then steps down one unit for each clock pulse, i.e. once per minute. When the counter reaches zero it closes the camera circuit, takes a picture, and returns to the original preset number. Thus, pictures can be spaced by any selected number of minutes.

While this is not the simplest method, in principle, for providing a variable spacing of pictures, it has the advantage of using standard components and avoiding intricate mechanical design and construction.

The case can be securely held by a substantial clamp round its centre, and a variety of mountings has been devised for it, some of which are shown in Figure 14.

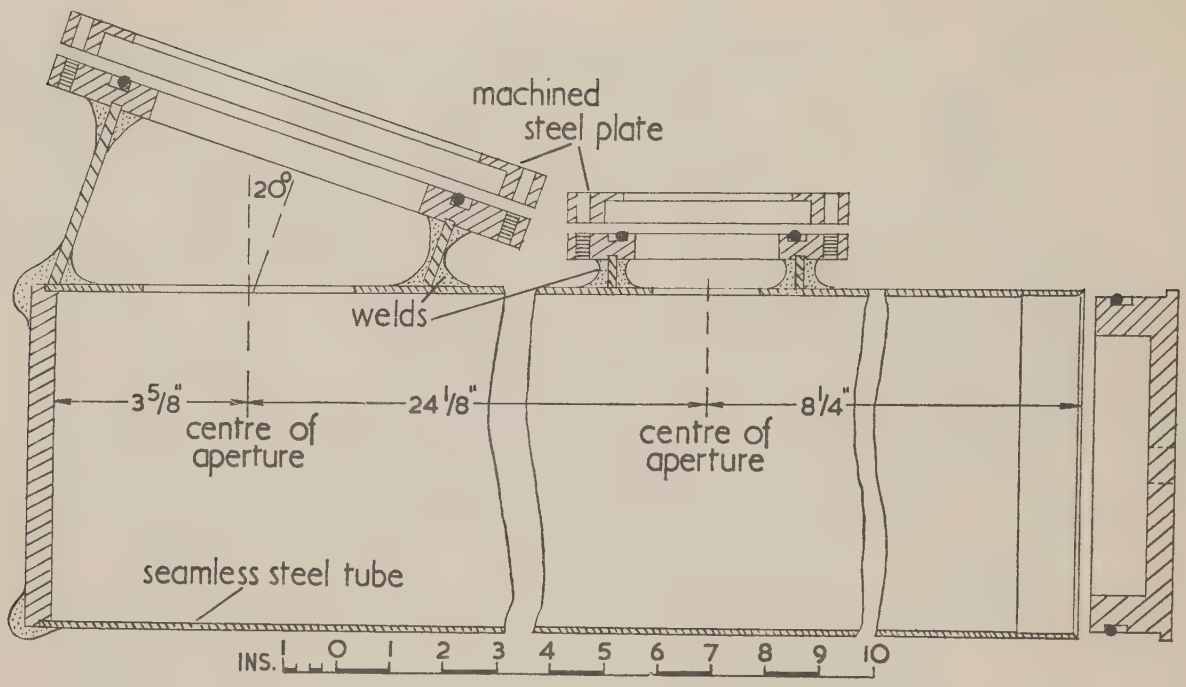


Fig. 12. Steel casing for otter-trawl camera.

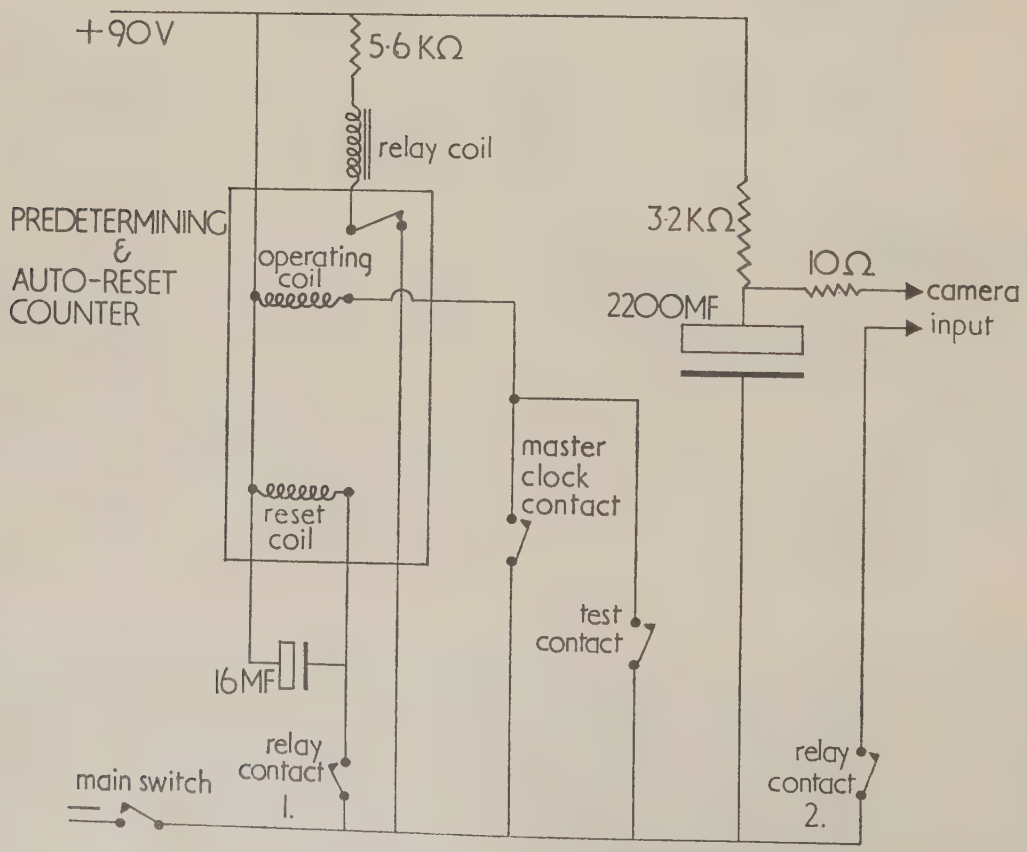


Fig. 13. Detailed circuit arrangements of otter trawl camera.

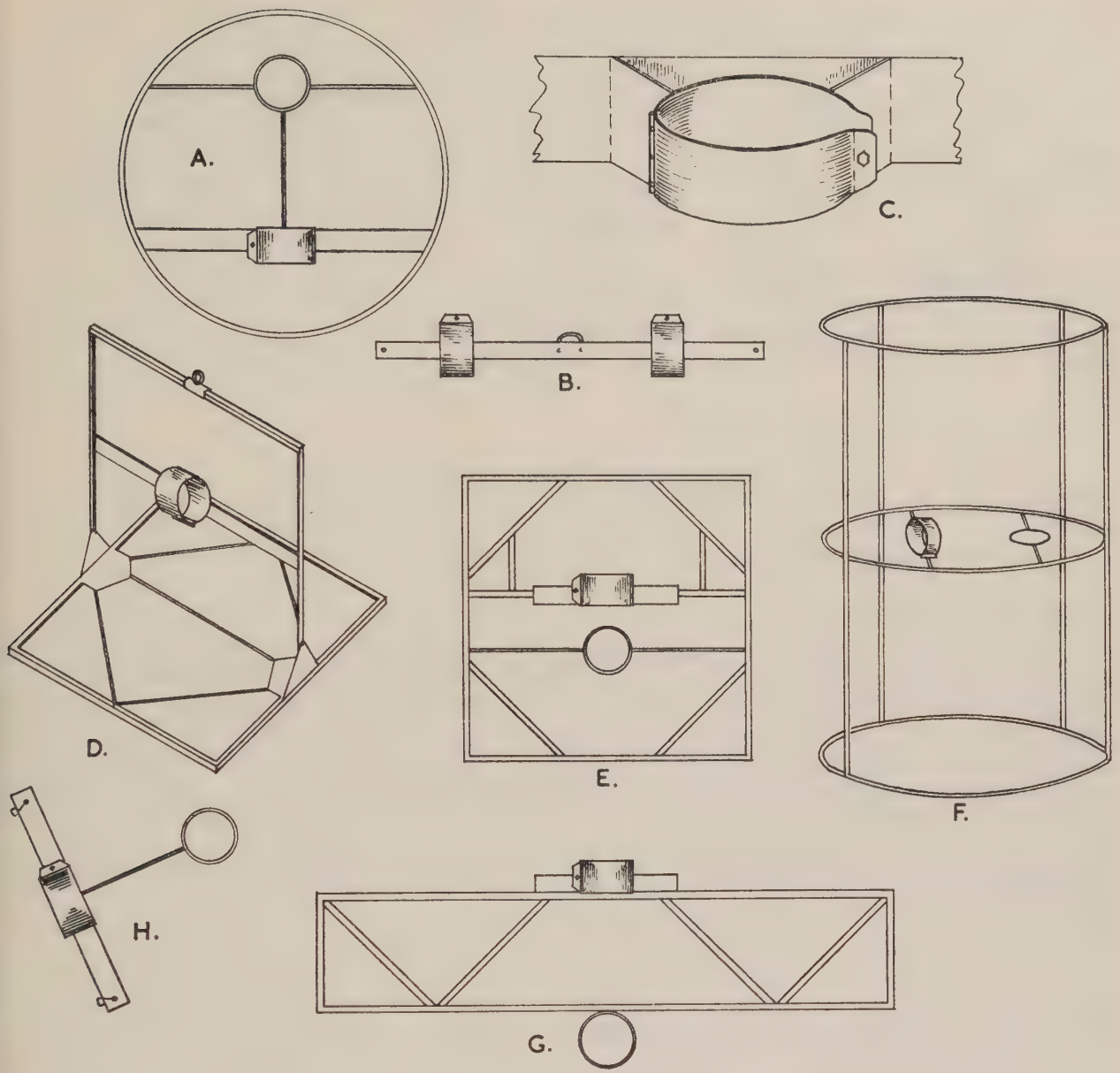


Fig. 14. Various mountings for otter-trawl camera. A, B, E, G and H are used by lashing appropriately to nets, the camera case being secured by the clamp (C) and the window fitting snugly in the ring. Net meshes can be cut as necessary and the free net secured to this ring, when viewing *through* the net is desired. The frame (D) is used on the sea-bed for population studies, and the cylindrical frame (F) can be placed within the cod-end of the trawl.

Trawl-Net Cine Camera

The case of this camera and that of the trawl-net still camera are identical. An Eumig 8 mm electric cine camera with *f*/2·8 lens takes the place of the Shackman camera, and a 75 W headlamp bulb replaces the flash tube. The circuit is shown in Figure 15. The only special feature is the timing mechanism, which provides a pre-set delay of up to 2 hours followed by a series of seven half minute runs every six minutes. The timing unit was adapted by mechanical modification of a timer made by 'Aspec' London Ltd, and available as surplus.

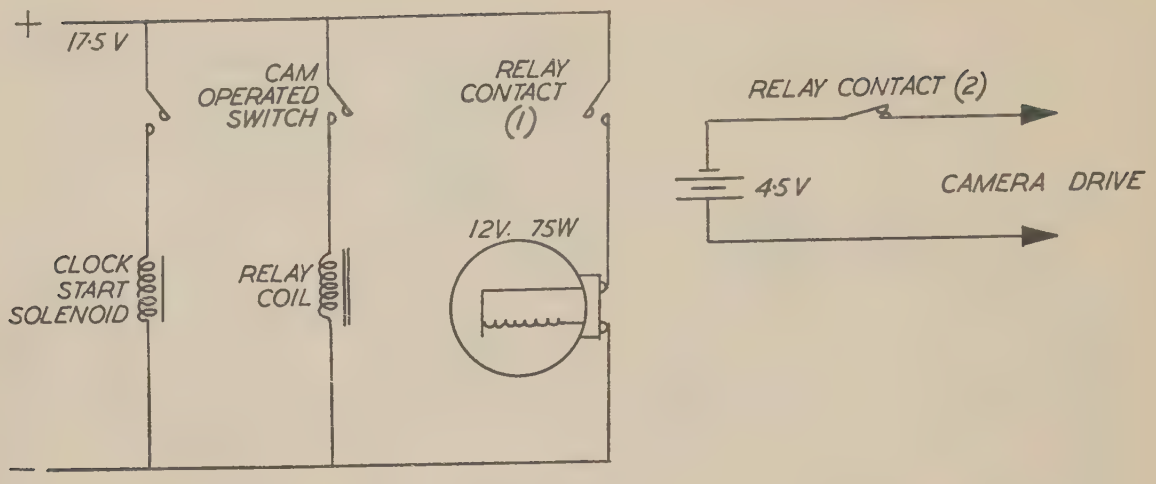


Fig. 15. Circuit arrangement of trawl-net cine camera.

Divers' 16 mm Cine Camera

A detailed account of this unit is unnecessary, since so many different versions of divers' cameras are in use throughout the world. However, this particular unit is cheap and compact and may be of interest (Plate III). The camera is the Vinten Scientific Camera with a 12 V battery supply and magazine loading. The lens is a $\frac{1}{2}$ inch (13 mm) $f/2{\cdot}8$; this very wide angle is advantageous in allowing a relatively close approach to large subjects such as nets, which is necessary in the normal conditions round the Scottish coasts, where the turbidity of the water limits the range of vision severely. The case consists of a tufnol tube, with end plugs of the same material, and the usual O-ring seal as illustrated in Figure 1*b*. Handles are clamped around the tube, and operation is by a sealed micro-switch placed for thumb control by the diver. The amount of film used is displayed on an illuminated dial visible through a window in the rear end of the unit.

APPLICATIONS OF UNDERWATER CAMERAS IN MARINE RESEARCH

Divers' Cameras

These are all hand-held cameras, either cine- or single-shot. Their value is not so much in direct research—for the diver can normally see as much as the camera—but in documenting and distributing the results of direct observations. In Aberdeen the mode of action of trawls and seine nets has been the principal interest (Dickson, 1961). After preliminary work, in which the photography was carried out by the late Lieut.-Cdr James Hodges, cameras were constructed at the Marine Laboratory and used by members of the staff to record the behaviour of full-scale and model nets in shallow water.

Sea-Bed Photography

Some of the results obtained have been described by McIntyre (1956), Parrish *et al.* (1959) and Stubbs and Lawrie (1962). Colour film has been found to be very convenient—since the lighting is constant, exposure can be made nearly correct and much of the processing work is eliminated by the routine service given by the film manufacturers. Colour also makes it easier to distinguish animals from background, and helps in the identification of species.

The planning of bottom surveys is mainly a matter of navigation and systematic position-keeping. Once a camera has been lowered it is obviously desirable to take a number of photographs rather than one, since the greater part of the labour is in getting the unit off the deck and into the water and in recovering it. Hence it is most convenient to make a series of traverses of an area in the natural direction of the drift.

The most serious limitation of photography as a bottom survey instrument is the prevalence of turbid water in many inshore areas, particularly in estuaries and near river mouths. Most of the Scottish area is workable in depths greater than 30 fathoms, but in shallower water perhaps a quarter of the area is apt to be unworkable on this account.

Even away from rivers, strong tidal streams or a heavy swell may stir up material from soft bottoms and thus prevent useful survey work by camera. Realization of this fact is, however, significant ecologically, and the advent of photography has tended to emphasise the need for a clearer understanding of visibility under water in different areas and under different weather conditions. Some examples of sea-bed photographs are given in Plates IV A and B.

Self-Contained Cameras

While incapable of giving the high definition of sea-bed cameras, self-contained cameras seem to have more applications in fisheries research. The present instruments have been built with emphasis on strength and reliability. However, there is room in this field for lighter, smaller instruments, even though some loss in optical performance is suffered.

The simplest way of using these instruments is to place them in a suitable frame and leave them on the sea-bed. Any suitable interval between exposures can be adopted, but it is sometimes convenient to spread the 200 photographs available over 24 hours, so that 8 minutes between exposures is a suitable interval. A research vessel can put down a network of cameras, and leave them to be recovered and reloaded on the following day.

Results obtained with this technique in estimating the density of herring on a spawning bed have been described by Craig and Priestley (1961). The method allows of such estimates being made and also gives valuable information about the behaviour and shoaling patterns of fish at different times of the day and night.

It will be realised that population studies call for a multiplicity of cameras, since an adequate volume of water and a variety of depth strata must be sampled. Some examples of results are given in Plate V.

Self-contained cameras are also useful in the study of fishing gear. Since most gear is prone to damage on rough ground, it follows that instruments attached to it will be subject to the same risk. This is unavoidable and is a reason for keeping the gear as cheap and as easily replaceable as possible. In fact the cost of one of the camera units used at the Marine Laboratory is comparable with the cost of a complete trawl—so that the instrument value at stake is not excessive. Unfortunately specialist equipment like this is not, and cannot readily be made, as replaceable as standard fishing gear. Experience shows that progress in this field must depend on sufficient equipment being available, so that the loss of one or two units does not result in the abandonment of a scientific programme.

The equipment has been used so far on trawl gear and on salmon bag-nets. On the trawl, which is probably of the greater general interest, the camera unit is clamped to a frame which in turn is lashed in appropriate positions on the net. For work inside the cod-end a special frame is used, consisting of two hoops joined to make a cylinder that can be slipped into the net. The frames are buoyed with trawl floats so as to offset the weight of the unit and to minimise distortion of the net. So far many photographs have been taken of the region just forward of the groundrope to determine whether fish in this region are swimming away from the net (Parrish *et al.*, 1962). Pictures have also been taken from various points of vantage to study the shape and flow of the net and the shape of the meshes. Cod-end films have been taken with the 8 mm cine camera to obtain information about the behaviour of fish and their mode of swimming inside the trawl. Some examples of pictures taken by this method on trawl gear are given in Plates V and VI.

In this discussion the authors have concerned themselves with the camera equipment, its applications and potentialities. The results of these studies will be described in due course by the various experts concerned, to whom the camera has become a recognized research tool.

SUMMARY

The various items of equipment used in underwater photography and the techniques employed in their application are discussed on the basis of the experience gained in work at the Marine Laboratory, Aberdeen. Four types of camera and the uses to which they are put in fisheries research are described in detail. Engineering drawings and electrical-layout diagrams are given for these units as well as examples of underwater photographs of substrates, fish and gear.

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APPENDIX I

A Note on the Need for Correction of a Camera Lens Used with a Plane Window Underwater

Clear pictures of a level sea bed are required using a camera pointing vertically downward. For convenience of manufacture a plane glass window of sufficient thickness to withstand the water pressure is used.

Two distinct optical errors occur—chromatic aberration, due to the non-uniform refraction of the water, and distortion, which causes the image of the level sea-bed to lie on a curved surface.

Chromatic aberration

Consider the observing eye or lens E to lie immediately above the water surface (Fig. 16). Effects due to the window itself may be neglected in comparison with the effects due to the water. This may be justified theoretically, and has been amply demonstrated by experiment.

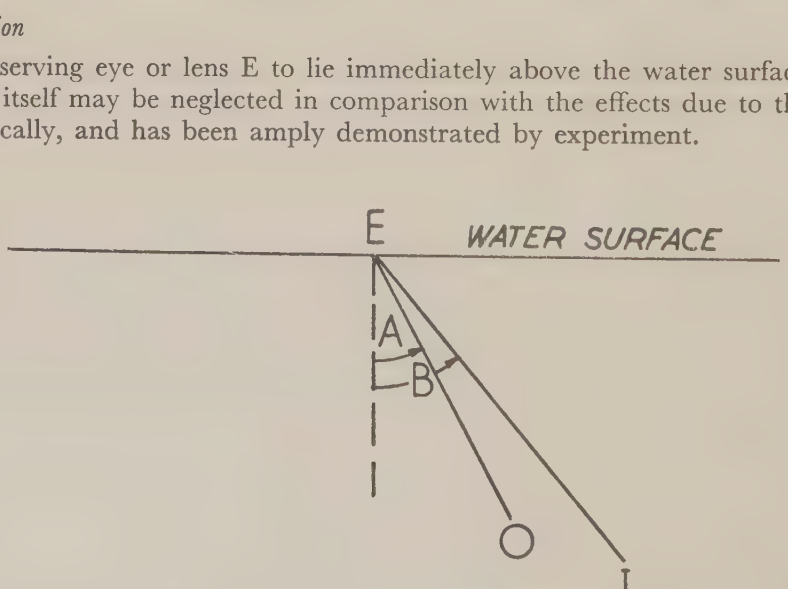

Fig. 16

Let an object O on the sea bed lie at an angle A to the normal through E, and the image I then lies at an angle B to this normal given by

$$\sin B = n \sin A$$

where n is the refractive index of the water for light of some particular wavelength.

Differentiating with respect to n

$$\cos B \, dB = \sin A \, dn = \frac{1}{n} \sin B \, dn$$

$$\text{or } dB = \frac{1}{n} \tan B \, dn$$

To appreciate the magnitude of this effect on the picture reference should be made to Figure 17. The effect of the aberration is to draw out the image of a point into a radial line.

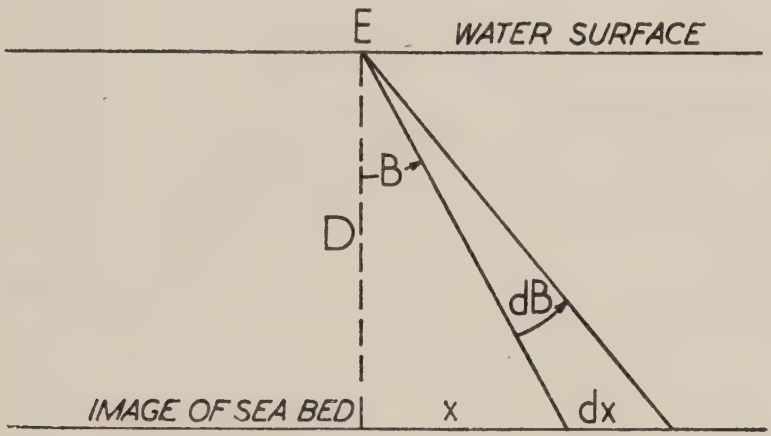

Fig. 17

Since the image is at an angle B from the normal, its apparent distance from the centre of the field is given by $x = D \tan B$, where D is the perpendicular distance from the lens to the image of the sea-bed.

Clearly then

$$dx = D \sec^2 B \, dB$$

$$= D \sec^2 B \frac{1}{n} \tan B \, dn$$

As a practical example let D = 54 inches, n = 1·34, dn = 0·025, B = 26°, where n refers to sea water, and dn corresponds to the difference between the wavelengths Na 5893 Å (yellow) and Sn 3034 Å (near ultra violet).

The value for dx comes out to 0·61 inches, i.e. the image of a point is drawn out into a line of this apparent length. This is a serious deficiency, and ought to be reduced to one-tenth if possible.

Distortion of a level surface

The position of the image of an object O on the sea-bed, whose position is defined by R and A, must be found (Fig. 18). The image I is fixed by considering the angular shift seen by an observer moving

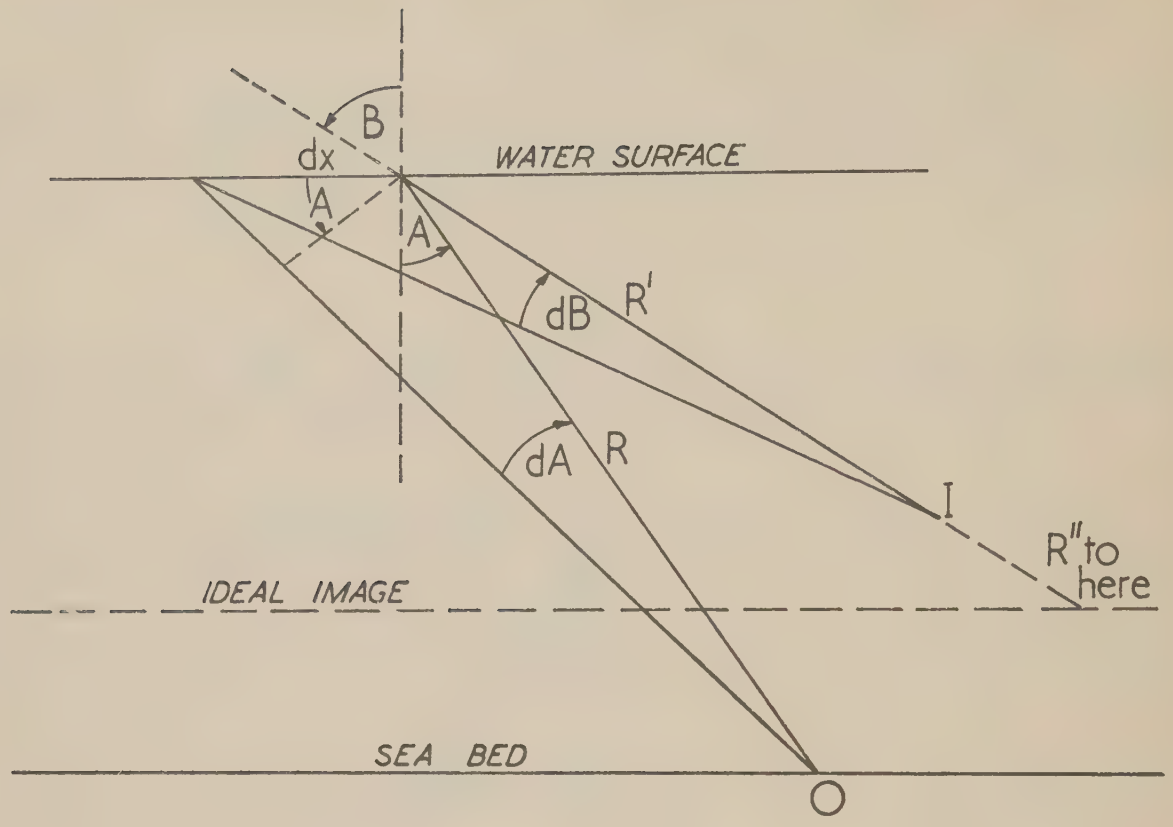

Fig. 18

through a small horizontal distance dx. The observer is supposed to be immediately above the water surface. Let the position of the image be defined by R′ and B.

$$\sin B = n \sin A \qquad \text{so } \cos B\, dB = n \cos A\, dA$$

$$\text{i.e. } \frac{dA}{dB} = \frac{1}{n}\frac{\cos B}{\cos A}$$

$$\text{now } dx = \frac{R\, dA}{\cos A} \text{ but also } dx = \frac{R'\, dB}{\cos B}$$

$$\text{so } R' = \frac{R \cos B}{\cos A}\frac{dA}{dB} = \frac{R \cos B}{\cos A}\frac{1}{n}\frac{\cos B}{\cos A} = \frac{R}{n}\frac{\cos^2 B}{\cos^2 A}$$

$$\text{i.e. } R' = \frac{R}{n}\frac{\cos^2 B}{1 - \sin^2 A} = \frac{R}{n}\frac{\cos^2 B}{1 - \dfrac{\sin^2 B}{n^2}} = \frac{R}{n}\frac{n^2 \cos^2 B}{n^2 - \sin^2 B}$$

$$\text{i.e. } R' = \frac{R\, n \cos^2 B}{n^2 - \sin^2 B}$$

For the central ray, the image of the sea-bed is at a distance $\frac{H}{n}$ from the lens, where H is the actual distance from lens to sea-bed. The lens being corrected for flatness of field is focused on a level surface indicated on the diagram as 'Ideal image of sea-bed'.

The distance R'' in the direction B to a point on this ideal image is of course

$$R'' = \frac{H}{n \cos B} \text{ and so the ratio } \frac{R'}{R''} \text{ is given by}$$

$$\frac{R'}{R''} = \frac{Rn \cos^2 B}{n^2 - \sin^2 B} \quad \frac{n \cos B}{H} = \frac{1}{H} \quad \frac{Rn^2 \cos^3 B}{n^2 - \sin^2 B}$$

$$\text{but } R = \frac{H}{\cos A}$$

$$\text{so } \frac{R'}{R''} = \frac{n^2 \cos^3 B}{\cos A \, (n^2 - \sin^2 B)} = \frac{n^2 \cos^3 B}{(n^2 - \sin^2 B) \sqrt{(1 - \sin^2 A)}}$$

$$= \frac{n^2 \cos^3 B}{(n^2 - \sin^2 B) \sqrt{1 - \frac{\sin^2 B}{n^2}}} = \frac{n^3 \cos^3 B}{(n^2 - \sin^2 B)^{3/2}}$$

For a practical example again let $n = 1{\cdot}34$, $B = 26°$, when the value of $\frac{R'}{R''}$ comes out to 0·86. That is to say that if the lens is correctly focused on the centre of the field, the image near a corner of the field is 14% too near to be in focus. This error can be appreciable with a long-focus lens of large aperture.

APPENDIX II

DESIGN OF THE UNDERWATER UNILITE LENS

by C. G. Wynne, B.A., Ph.D., F.Inst.P., Imperial College, London

The chromatic aberrations arising from a plane parallel window separating an object space in water from a camera in air involve, in general, both a chromatic difference of focus (a displacement of the image surface of different wavelengths along the direction of the lens axis) and a chromatic difference of magnification. For an object at infinity, the chromatic difference of focus is zero; but where the object distance is large compared with the focal length of the camera lens, these longitudinal chromatic effects are negligibly small. The transverse chromatic effects (chromatic difference of magnification) are not dependent in the same way on object distance, and as explained in Appendix I, become very large over quite moderate field angles.

First order chromatic aberration theory is adequate for the correction of this transverse chromatic aberration, but it follows from this theory that correction of the aberration is not possible by any very simple addition to a normally corrected photographic lens. If, for example, a thin afocal lens, introducing no aberrations but chromatic ones, be placed in front of a normal photographic objective, as was suggested by Thorndike (1955), then the primary transverse chromatic aberration that such an element introduces is equal to its longitudinal aberration multiplied by a factor dependent on its distance from the entrance pupil of the photographic lens. Such a system can be designed to correct the transverse chromatic effects of the water, but only by introducing an undesirable chromatic difference of focus. This latter can be reduced by increasing the distance of the afocal element from the taking lens, for example by placing it outside the window in water: this may give rise to mechanical difficulties, and in any case such expedients can only reduce, and not eliminate, the longitudinal chromatic aberration, so that there remains some loss of resolution on the whole picture area.

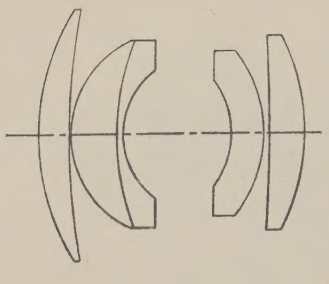

Fig. 19 Wray unilite—standard type.

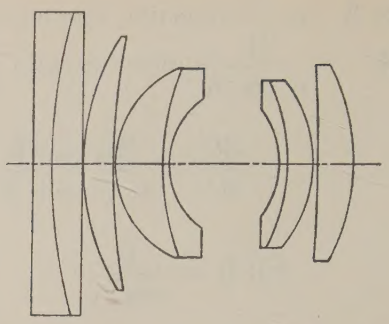

Fig. 20 Wray unilite for use underwater.

Correction of the transverse chromatic aberration, without introducing a longitudinal error, can be achieved by modifications of the two halves of a normal photographic lens that lie before and behind the stop, in such a way that the longitudinal aberration changes are equal in magnitude but opposite in sign, but the transverse terms, which are then of the same sign, compensate for the effect of the water refraction. The Wray *f*/2 Unilite form of lens (Fig. 19) lends itself fairly readily to this treatment. The rear meniscus lens, which is a single piece of glass, can be compounded into two lenses cemented together, having the same refractive index as the original single component, but different dispersions, so as to introduce enough longitudinal chromatic aberration to compensate for that of an afocal cemented component placed close in front of the system, the two changes together combining to give the required transverse chromatic aberration (Fig. 20) Virtually perfect correction of the chromatic effects of the water refraction is thus achieved, without introducing any deterioration of the lens performance in other respects, and with only a small increase in the length of the system.

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